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Education Effects on Participant's Awareness: Zero Waste Management Education in Istanbul Technical University (ITU) Ayazağa Campus

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Abstract

Turkey Ministry of Environment and Urbanization published Zero Waste (ZW) Regulation in July 2019. "Zero Waste Management Act" (ZWMA) was started in Istanbul Technical University (ITU) Ayazağa Campus as a part of a larger scale project called as "Green Campus". Education is first and crucial step to success in the sustainability acts. The aim of this study was to determine ZW management education effects on participant's knowledge. In this scope; ZW educations were given to administrative staff in 2019-2020 academic year. This study was conducted by using online questionnaires. The questionnaires included questions related to educational content and instructor, participant's willingness to ZW management and technical aspects of ZW approach. The results showed that 82% of the participants understood waste management (WM) hierarchy priority clearly and 93% understood recycling containers classification in the new ZWMA. However, they were confused about current WM practices in Turkey, totally 52% of participants chose recycling, composting and recovery as most frequently applied WM practices instead of landfilling. Based on the results it is understood that education has a significant positive effect on participant's knowledge. This study contributes to existing knowledge of WM by providing data about participant's awareness and it would be pioneer to further sustainability activities in the campus.

Key words

Education, higher education institutions (HEIs), sustainability, university, zero waste.

1. INTRODUCTION

Sustainability term had stepped into human's life in the 1970s with the understanding of human beings cannot survive without the "environment" [1]. Sustainable development was defined as *"meeting the needs of the present without compromising the ability of future generations to meet their own needs."* by UN [2]. Higher Education Institutions (HEIs) have started interest with the sustainability concept after the UN Stockholm Conference in 1972 [3]. However, UN- Conference on Sustainable Development in 2012 (Rio+20) was a milestone in terms of the importance of the relationship between (Sustainable Development Goals) SDGs and education [1].

Universities have new responsibilities for reaching SDGs after the Rio conference [1]. University campuses are complex systems where all education and researches are carried out by consuming material, energy and water [4]. Sustainability in universities was defined as *"A higher educational institution, as a whole or as a part, that addresses, involves and promotes, on a regional or a global level, the minimization of negative environmental, economic, societal, and health effects generated in the use of their resources in order to fulfill its functions of teaching, research, outreach and partnership, and stewardship in ways to help society make the transition to sustainable life-styles*." by Velazquez [5].

HEIs are basically creating ideas and solutions by consuming products where they also have environmental, economic and social responsibilities for the society. Besides, universities should be pioneer to other institutions. Hence, universities are morally responsible for finding practical and theoretical solutions to environmental problems [6]. In this purposes, universities have been attempting various plans to become more sustainable or green campuses [7]. However, it was recently discovered that education is a key for long term success of sustainability goals in universities. Education activities regarding sustainability could be planned formal or non-formal way. Conferences, seminars and workshops are considered as non-formal education while undergraduate, graduate courses and certificate programs defined as formal education [5]. Formal education could be done via distance learning or on campus under the scope of curriculum [5]. Non-formal education could be done any time during an academic year without strict plan and date unlike the formal education.

Istanbul Technical University (ITU) started sustainability educations with Zero Waste Management (ZWM) in September 2019. Educations were conducted under the scope of non-formal education. However, ITU sustainability vision includes formal education for following years. ZWM was chosen as a first education topic because the Ministry of Environment and Urbanization was published Zero Waste Regulation in July 2019 [8]. According to regulation, universities are responsible for reaching zero waste (ZW) goal to landfills. Waste management (WM) studies have generally focused on environmental consequences and left out other sustainability pillars which are economic and social [9]. Hence, this study is expected to be the first step of "ZWM goal" developed within the scope of a sustainability vision at ITU. It will be an important opportunity to see education effects on participant's awareness and the changes in WM activities.

The aim of this study is to determine ZWM education effects on participant's knowledge. In this scope; education was given about ZWM and sustainability to ITU Ayazağa administrative staff. Also new ZWM plan in ITU Ayazağa Campus was introduced to participants. Then, a questionnaire was conducted to learn participant's knowledge and suggestions about ZWM activities. Environment, economy and social aspects are three pillars of sustainability and they should examine simultaneously for sustainability goals. In this scope; questionnaire results will be considered while planning future ZWM activities in the campus. The previously published research using surveys were conducted with campus stakeholders to understand their awareness and willingness about sustainability initiatives [3],[10]. This study will contribute to the current literature with adding information regarding successful sustainability activities in particular WM in HEIs.

2. MATERIAL AND METHOD

ZW educations were given to administrative staff one in fall and three in spring semesters in 2019-2020 academic year. Education information was covered not only about ZW but also on sustainability, WM practices in Turkey and circular economy concepts. Since all education content and lecturer were exactly the same in all four educations, it was possible to evaluate the overall results together. Questionnaire sent to participants online after education and 10 days have given them to answer. Questionnaire was answered by totally 89 people.

The questionnaire was aimed to learn (i) participant's thoughts about education and (ii) participant's knowledge about educational content. The 5 point Likert scale questions were used to learn the participant's thoughts about education itself. Multiple choice questions were used for educational content. Also an open ended question was asked to learn suggestions of participants regarding to ZWM activities on campus and further educations.

The possible limitation of the study could come from non-responders, participants who participated in education but did not answer the questionnaire. However, their ratio is below than 10 % of the participant's and this ratio can be accepted according to previous survey study [10].

3. RESULTS AND DISCUSSION

One of the important aspects of the questionnaire is to learn the participant's thoughts about ZW education and the results are shown in Table 1. According to the results 87.2 % of participants were found education successful and efficient. Also, 82.2% thought that their awareness about environmental issues was increased after education.

Table 1. Participants thoughts about education (%)

Education (%)	**Strongly disagree**	**Disagree**	**Neither agree or disagree**	**Agree***	**Strongly agree***
Education contribution to you is very high and it is helpful for raising your awareness	1.1	2.2	14.4	34.4	47.8
Education is generally successful and efficient	0.0	1.1	11.2	29.2	58.4
Clarity of presentation/education is high	0.0	1.1	10.0	38.9	50.0
The performance of the educator/lecturer is enough and efficient	1.1	0.0	10.0	35.6	53.3

*Sum of strongly agree and agree is accepted as understanding of the concept

Results in Table 2 shows that 82.4 % of the participants understand WM hierarchy priority clearly. However, they are confused about current WM practices in Turkey, totally 52% of participants choose recycling, composting and recovery as a most frequently applied WM practices instead of landfilling. Even though recycling rate has increased in recent years, landfilling is still the most applied WM method in Turkey [11].

Table 2. Participants knowledge about WM (%)

WM questions (%)	**Disposal**	**Recycle**	**Reuse**	**Reduce**	**Prevention**
Which one is the first step of waste hierarchy (priority)?	0.0	1.1	0.0	16.5	82.4
	Recycle	**Recovery**	**Compost**	**Incineration**	**Landfill**
Which WM method is the most practiced method in Turkey?	34.8	6.7	10.1	5.6	42.7

The waste will be separated four waste categories in order to increase recycling on campus. Blue container will be used for paper and cardboard while green for glass, yellow for plastic/metals and grey for other wastes. It is apparent from Table 3 that 93.3% participants understand recycling containers separation in the campus. 94.4 % of participants, known glass and paper wastes container color right while 87.6% known plastic wastes colors.

Table 3. Participants knowledge about the ZWM in ITU after education (%)

ZWM in İTÜ (%)	**1**	**2**	**3**	**4**	**<4**
What will be the number of containers in ITU-ZWM ?	0.0	0.0	5.6	93.3	1.1
Which one is the color of glass wastes ?	**Red**	**Blue**	**Green**	**Yellow**	**Grey**
	0.0	1.1	94.4	3.4	1.1
Which one is the color of paper wastes ?	**Red**	**Blue**	**Green**	**Yellow**	**Grey**
	0.0	94.4	1.1	2.2	2.2
Which one is the color of plastic wastes ?	**Red**	**Blue**	**Green**	**Yellow**	**Grey**
	0.0	1.1	9.0	87.6	2.2

Education also included information related to economic aspects of sustainability since three main pillars of sustainability, which are environmental, economic and social, are merged each other. *Which economy approach is preferred for the ZW goal?* question was asked in questionnaire and most of the participants understood the circular economy and ZW relationship. According to Figure 1, most of the participants (69.3%) chose circular economy is more sustainable economy approach which encourages waste upcycling activities for reaching ZW goal.

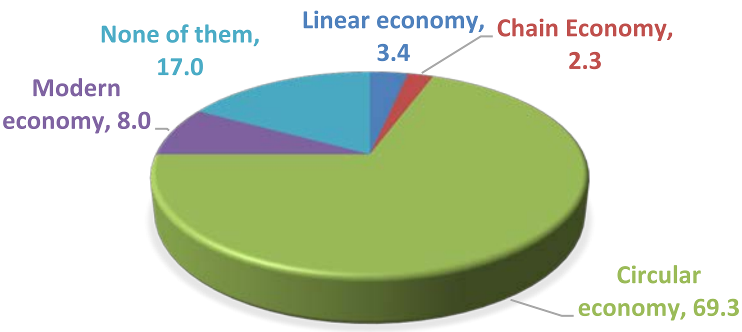

Figure 1. Which economy approach is preferred for the ZW goal?

The questionnaire also had an open ended question to learn participant's suggestions about further ZWM activities and future educations. Most of the participants were pleased with education and they recommended to give this education regularly to all stakeholders of the campus. They also suggested to create posters and slogans about ZWM to change perceptions of people. There were different opinions about "waste reduction in daily life" examples in education. While some participants were very pleased with examples other says they should be expanded to all activities in a daily life, for instance; energy and water savings in the university. Although the main goal was to measure the success of education, some participants complained about questionnaire itself, they were perceived the questionnaire as an exam. The knowledge of the participants about ZW was learned verbally before the education. The questionnaires were held after the education to "find out the success of the education". This situation prevented the comparison of before and after knowledge of participants by questionnaire. Therefore, the difference in participant's knowledge can be followed by behavioral changes for instance; the change in the amount of waste and recycling performance in the campus.

4. DISCUSSION

This study set out with the aim of assessing the effect of ZWM education on participant's knowledge. The results of this study in **Table 2** indicate that participants perfectly understood WM hierarchy priority, however; they were confused about current WM practices in Turkey. Although landfill was chosen as the most selected answer with 42.7% in the questionnaire, it is still far away from the real life. Almost 80% of the municipal wastes were still sent to landfills in Turkey [11]. A possible explanation of this result may be the main focus of the education, which is representing ZWM concept and its relationship with sustainability. Although current WM practices in Turkey were mentioned in the education, the main focus was on waste prevention and recycling options for reaching ZWM goal.

It is understood from **Table 3** that study was reached the main goal which is increasing participant's knowledge about ZWM activities. Even the least known question, which is the color of plastic waste containers, had 87% correct response. The one of the possible reason of this result is that plastic wastes container color is less known compared to paper and glass containers. Blue and green containers already exists in the current waste management system. However, even though red and yellow colors are new options in questionnaire no one selected red containers as answer for new ZWM activities in ITU. These results support the idea of education and sustainability activities have positive effects on participant's knowledge. A study conducted in Turkey concluded that students who took sustainability courses and/or studied at universities or where sustainability practices conducted, had tendency to research the sustainability subject personally [12]. Also, they had enough knowledge to define sustainability [12]. Similar work in Lithuania has shown that; green university students (universities applied to the UI GreenMetric Ranking system) are more sensitive to the sustainability activities than non-green university students [13].

The WM also has substantial economic consequences in addition to the environmental results. For instance; the recycling activities in campuses will contribute profit of university budget [14]. Hence, participant's awareness about economy and WM relationship is crucial and according to Figure 1. 69.3% of participants were familiar with circular economy concept after education.

Environmental changes depend on behavioral changes of the public [6]. Administrative staff is an important "stakeholder" on campuses, but this education must also be applied to other stakeholders. This suggestion also came from the participants at the open ended question in survey. Students are the most effective stakeholder group in terms of population. This kind of education attempts are important since they help to create a culture in campus even though the results are not seen right away [6]. It is also important that they carry this culture to their professional lives when they become alumni. Hence, university commitments on SDGs or other environmental topics should be compatible with curriculum to increase participation of campus stakeholders. This will help to increase student's awareness about sustainability and other environmental goals such as ZWM. Further studies on ZWM topic are recommended especially in order to follow education effects on behavioral changes of participants as well as change in WM performance of the campus.

5. CONCLUSION

The aim of this study was to understand education effects on participant's knowledge in aspects of ZWM. However, individual attempts are not enough. Clear vision and a management are essential for long-term success of sustainability. Sustainability activities in ITU have been continuing with top-down approach. It is understood from both face to face interviews and questionnaire results that people are willing to participate sustainability acts. However, they don't have any attempts before the initial act comes from the university management. WM has economic and social consequences besides environmental ones. Hence, this study is assumed as a crucial step for the sustainability studies in campus. As it is suggested by participants these educations should be expanded to all stakeholders on campus. Formal WM and sustainability education program should be included in all undergraduate curriculum.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest.

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The UI GreenMetric Ranking System: Analyzing Impacts of Categories on Overall Results

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Abstract

The UI GreenMetric Ranking system is celebrating tenth year anniversary in 2020. The UI GreenMetric has six categories which are; "Setting & Infrastructure" (SI), "Energy & Climate" (EC), "Waste" (WS), "Water" (WR), "Transportation" (TR) and "Education" (ED). The SI category has 15% of the total point while EC category has 21%, WR category has 10%, WS, T and E categories have %18. However, there is still missing points about the exact impacts of categories on overall results. Thus, the aim of this study is to exam previous years ranking results to understand details of category impacts on the UI GreenMetric ranking. The ranking data for the study were taken from the UI GreenMetric's official website. According to results; the EC category determines which university has the higher ranking if two university have the same total point. The WS, TR and ED categories are possible second effective categories however very rarely SI category has second place after EC. Ranking results were also examined for each continent and strong relationship between existence of developed countries and success of the UI GreenMetric performance of a continent was found. New certificates for categories such as "energy efficient campus of the year", "zero waste producer of the year", "water-saver of the year", "green path of the year" and "green producer/consumer of the year" are recommended for embracing categories and increasing their recognition. Besides the updates and change in the category indicators fee-free applications to the UI GreenMetric ranking system should be continued and details of the scoring system should be clarified in the guidelines.

Key words

Green campus, UI GreenMetric, Higher Education Institutions (HEIs), Sustainability, Sustainable Development Goals (SDGs)

1. INTRODUCTION

The solution of global problems such as staying in planetary boundaries and detention of climate change, depends on the positive steps have taken on a smaller scale such as city, district and even in university campus [1],[2]. Sustainable Development Goals (SDGs) have been developed as a solution to these problems. The triple bottom of sustainability is mandatory in order to fully realization and application of SDGs. Education sector has strong relationship with SDGs. Universities has a direct effect on their stakeholders such as students, employees, alumni, parents and have indirect effects on society [2], since universities are excepted as high-esteem [3]. SDGs Australia report; supports this theory by stating that "knowledge of universities and their unique position within society, have a critical role to play in the achievement of the SDGs" [4]. Also, universities are seen as living labs. SDGs and universities relationship has been discussed ambitiously in recent years [2]. Also, some studies showed that it is not possible to reach SDGs without education [4].

The relationship between Higher Education Institutions (HEI's) and the environment began with The Stockholm Declaration in 1972 [5]. The Talloires Declaration was signed in France in 1990 and it had become an important step for HEIs to focusing on environmental problems [5]. UNESCO stated that education is a necessity for sustainable development in 1994 [2]. While USA universities started to establish NGO's for sustainability projects Australian universities prepared strategic plans for reaching sustainability goals at the end of 90's [2]. The Rio + 20 Declaration in 2012 had five scopes for universities; "Teaching sustainable development concepts, encouraging research on sustainable development issues, greening of campuses, supporting sustainability efforts and fostering and engaging in international collaboration" [2]. After Rio Declaration, SDGs were established in 2015. The concept of green campus date back to the 70's, but it has started to gain importance since the 2000s. Related timeline was given in Figure 1.

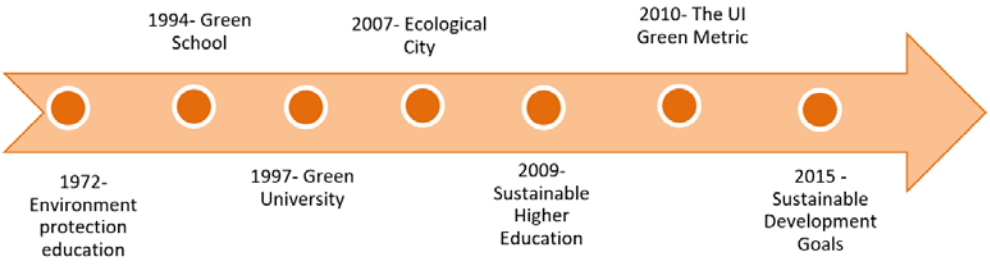


Figure 1. Timeline summary of Green Campus concept, adapted from Tan et. al [2].

"The majority of university campuses in Europe and North America have been involved in greening initiatives over the past two decades, particularly through the development of environmental policies, implementation of action plans, restructuring and signing of courses and research programs" as stated by Arroyo [6]. Today, climate change mitigation and campus sustainability have become a global concern for university leaders. Many world universities are taking steps to fight climate change by reducing their carbon footprint and managing sustainability activities [7], [8]. Also, previous studies claimed that per capita energy and water consumption in university campuses were higher than other residents [2]. These recent studies have enabled to accept campuses as mini cities [9] and the green campus concept is presented as a solution for existing problems.

There is no single target for green campus and campus sustainability concepts in the literature [10]. Every institution sets their own goals towards a sustainable campus. Previous studies have established holistic and comprehensive concept suggestions for embracing sustainability in HEIs [9],[11]. These recommendations have been adopted by many universities and scholars. The green campus projects and academic studies have increased rapidly since 2008. The number of publications containing the "green campus" keyword (Figure 2) in the last 35 years supports this theory. Also, green campus activities and other university projects are classified in different ranking systems in recent years.

University rankings have become popular and representative for university's reputation besides academic publications especially in the last twenty years [7], [12]. The rankings, cover a variety of topics such as research, academic reputation, education, number of female students and international students [7]. The importance of research and academic reputation is in the first place in most of the university rankings while they are followed by education. However, environmental problems have little or no attention [7]. The QS ranking system is one of the ranking systems in the world and it ranks 3000 universities each year according to; academic reputation, employee reputation, academic staff/student ratio, international student and citation per faculty [14]. However, new certificate and ranking systems that highlight sustainability and campus relationship have emerged in the early 2000s with the new wave of sustainability and green campus concept. One of the pioneer and famous system is The Sustainability Tracking, Assessment & Rating System (STARS) which was established in 2006 by the Association for the Advancement of Sustainability in Higher Education [15]. The STARS system consists energy, buildings, waste, water, food & dining, grounds, purchasing and transportation as main categories [14], [16]. STARS classifies universities with certificates instead of competing universities among each other [5]. The UI GreenMetric system was established in 2010 which had been inspired by STARS, Greenship, and Holcim sustainability assessment systems [17]. The UI GreenMetric has encountered increasing interest from all over the world since it does not have any precondition and fee for the applications [15].

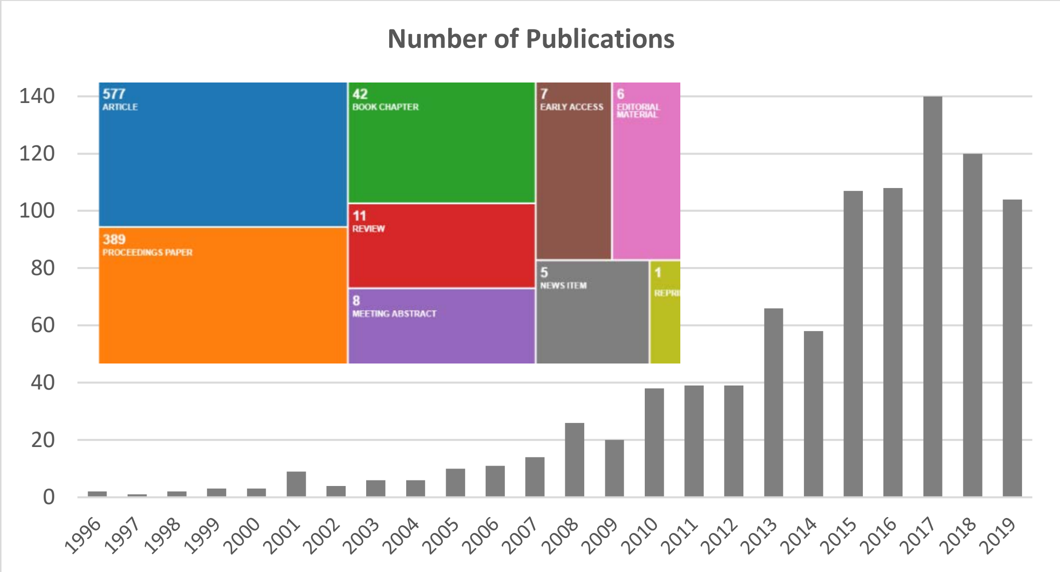


Figure 2. Number of "Green Campus" publications by years in Web of Science [13].

The UI GreenMetric has six categories which are; "Setting & Infrastructure" (SI), "Energy & Climate" (EC), "Waste" (WS), "Water" (WR) "Transportation" (TR) and "Education" (ED) in current scoring system. The UI-Green Metric has been regularly updated since the beginning but it made the biggest change in terms of categories in 2012. The 23 indicators under five categories were used in the 2010 while 34 indicators were used in 2011. Old scoring system was changed in 2012 and **the ED category** was added into scoring system. The names and percentages of the categories of The UI GreenMetric were shown in **Figure 3**. The **EC** category still has the highest impact. The **SI category** used to have the second place in terms of impact on overall results with 24%, now it has the fifth highest impact with 15% [18]. The **WS, TR** and **ED** categories have %18 while **WR** category has 10% of the UI GreenMetric total score. Although there was no change regarding percentage weight of categories after 2012, the indicators within the categories continued to change. The new indicators related to carbon footprint were added to the EC category in 2015. In addition, **WR and TR** categories were updated [18]. The new indicators were established and old indicators such as "*planted vegetation, energy efficient appliances usage, smart building, elements of green building implementation, the greenhouse gas emission reduction program, all of waste and water criteria, the ratio of parking area to total campus area , transportation initiatives to decrease private vehicles on campus, the transportation program designed to limit or decrease the parking area on campus, shuttle services, Zero Emission Vehicles (ZEV) and pedestrian policy on campus, existence of published sustainability report*" were updated to strengthen the relationship between SGDs and universities" as stated in the UI GreenMetric 2020 Guideline [18].

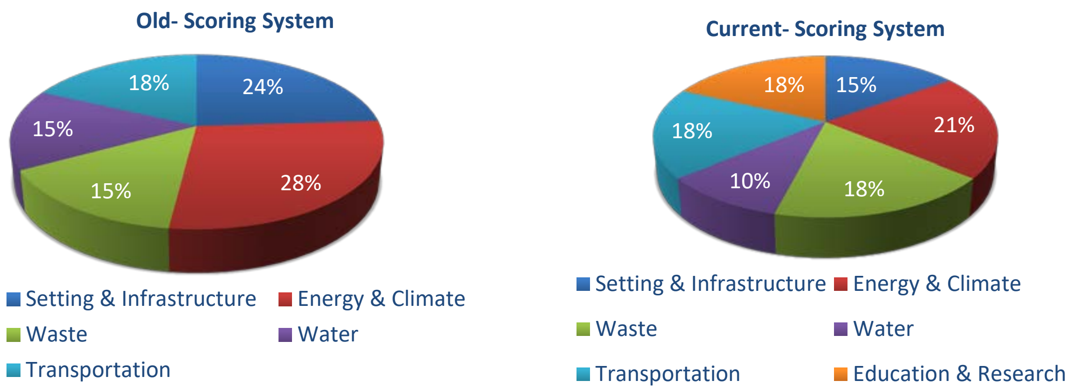


Figure 3. Old and current scores of categories in the UI GreenMetric [7], [18].

Universities submit their applications via a questionnaire in the UI GreenMetric's official website. Submissions start in May and continue until end of October. Results are announced in December. While evidence uploading is mandatory for some questions, in others it up to university's choice. However, there is no direct relationship between the number of evidence requested in a category and the total score of the category. For instance, while six evidences are requested in the SI and WS categories, four evidence are requested in the EC category which has the highest effect with 21%. The UI GreenMetric have received applications from 35 different countries and 95 universities in 2010. These numbers have gradually increased and reached 780 universities from 85 countries by 2019. Despite the increasing interest in academic studies about the UI GreenMetric [1], [19-21], and continues updating of the ranking system, there are still unknowns such as evaluation of applications and exact effects of categories on overall results. Thus, the aim of this study is to examine previous years ranking results for understanding details of the UI GreenMetric's ranking system.

2. MATERIAL AND METHOD

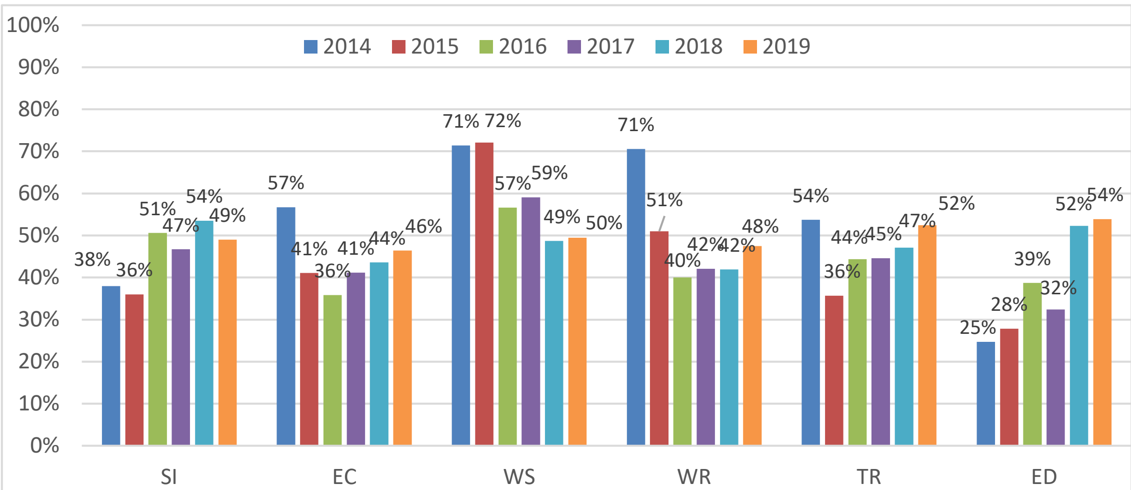
Literature research was done using Scopus, Web of Science (WoS) and Google Scholar search engines. The "Green Metric", "green campus", "sustainability and university" keywords were used to find previous publications. After initial search, snowball method was followed. Additional research was done in WoS by using the keyword "green campus" in order to specify number of academic studies. This study was conducted to clarify impacts of categories on overall results. The ranking data were taken from the Green Metric's official website and analysis were carried out by using data between 2014 and 2019.

3. RESULTS AND DISCUSSION

It is known that the UI GreenMetric ranking system has positive effects on sustainable universities and green campus concepts. The number of universities applying to the UI GreenMetric have increased and this shows increasing attention of green campus activities in universities. According to search results; 577 articles and 389 proceeding papers have been published until June 2020. A significant increase in the number of publications has been observed after 2012. The highest number of publications belongs to 2017 as it can be seen in Figure 2. According to the UI GreenMetric 2020 guideline 64 publications refer to the UI GreenMetric ranking system in their studies [18]. The UI GreenMetric ranking system was established in 2010 however discussions and studies about the system still continue. Previous studies were mostly focused on content of the UI GreenMetric ranking system and provided valuable suggestions [1], [19-21]. In this study, we tried to determine the category which has the highest impact on success (ranking) of universities by evaluating previous year's results. In order to understand that, universities which have the same overall score but also have different rankings were compared. A preliminary study was carried out by using different ranking ranges averages scores, in order to give suggestions to universities for improving their GreenMetric performance. In addition, category results were compared by continents to understand whether the location of the universities has an effect on the results.

3.1. World overall ranking performance by categories

The UI Green Metric official site has been sharing category results since 2014. Therefore, evaluations were made for the years 2014-2019. While the number universities applied to the UI GreenMetric was 361 in 2014, this number has increased and reached 780 in 2019. The new universities may affect the overall results in both ways, increase or decrease, however they still provide necessary information about general trend of the university performances. The ratio of the maximum score that can be obtained for each category and the average scores of all applied universities were given in Figure 4.



SI: Setting & Infrastructure, EC: Energy & Climate, WS: Waste, WR: Water, TR: Transportation, ED: Education

Figure 4. World overall ranking performance by categories (receiving score average/ maximum score of category (%))

The **SI** category performance has decreased in odd-numbered years while it has increased in even-numbered years. The general trend of the **SI** category results show that increase was more than the decrease. Although the **EC** category was experienced a sudden decline in 2015, it has an increasing trend in recent years. The **WS** category has always remained above 50% except in 2018. The **WR** category has experienced a sudden decline in 2015 and 2016, although there is an increase in the following years, it is still below 50%. The **TR** category has increased except for the year 2015. The **ED** category has showed an increase except for 2017 and became the category with the highest increasing trend.

Table 1. Average score of universities in different ranking ranges in 2019.

Ranking range	SI (1500)	EC (2100)	WS (1800)	WR (1000)	TR (1800)	ED (1800)	Total Score (10000)
1-49	1066	1579	1606	838	1459	1562	8110
50-99	916	1387	1475	788	1316	1467	7348
100-199	841	1235	1231	686	1194	1276	6461
200-299	811	1089	1109	572	1089	1108	5778
300-399	759	996	922	484	1015	1009	5185
400-499	738	888	797	438	900	888	4649
500-599	679	804	715	358	778	818	4151
600-699	590	707	457	278	678	667	3376
700-780	416	509	243	102	412	380	2063

SI: Setting & Infrastructure, EC: Energy & Climate, WS: Waste, WR: Water, TR: Transportation, ED: Education

In order to the understand the category which deserves more attention and the priorities for universities to become greener and more successful in the UI GreenMetric ranking system in the coming years, the average scores of certain ranking ranges were calculated using 2019 data. It was seen from Table 1 that ranking ranges scores of each category stayed behind if they had lower ranking range in the overall results. For instance, 300-399 range universities had average overall results with 5185 and stayed behind the 200- 299 range (5778 overall point) while all other categories also stayed behind. To find an answer to *"What would universities do to be in the upper range?"* question a heat table was created in Table 2 using Table 1. According to Table 2, there is a 10% difference between the average performance scores of universities between 1-49 (1579 point) and 50-99 (1387 point) for the **EC** category. As it can be understood from Table 2, a university that wants to be in the top 49 and whose ranking is currently between 50-99 should try to improve their institutions in the **EC, WS, ED, SI, WR** and **TR** categories, respectively. The heat table was prepared using average scores. Therefore, the university could be already successful in a certain category even though average score (heat table) suggests an improvement. Therefore, every university should develop their own plan by considering economic feasibility and social factors of their institutions.

Table 2. Heat table of range difference (%) - (What would universities do to be in the upper range?)

Difference between ranges (%)	SI	EC	WS	WR	TR	ED	Total Score
(1-49)-(50-99)	8	10	9	7	5	8	5
(50-99)-(100-199)	9	5	7	14	10	7	11
(100-199)-(200-299)	7	2	7	7	11	6	9
(200-299)-(300-399)	6	3	4	10	9	4	5
(300-399)-(400-499)	5	1	5	7	5	6	7
(400-499)-(500-599)	5	4	4	5	8	7	4
(500-599)-(600-699)	8	6	5	14	8	6	8
(600-699)-(700-780)	13	12	9	12	18	15	16

% difference with higher ranking changes	1- 3	4-6	7-9	10-13	> 13

3.2. World ranking performance by continents

The UI GreenMetric has been sharing results on a continent basis since 2017. The highest participation was from Asia with 48% (373 universities) while lowest participations belongs to Africa (2% with 14 universities) and Oceania (0.5% with 4 universities) in 2019. The universities in Oceania continent had the highest average points, while African countries had the lowest average in overall results. The %50 (7 universities) of the African universities had 3500 or less points. It is thought that universities from the higher GDP countries like in Oceania have effect on these results. When the categories weree examined, the **SI** category had the highest average score in Oceania, while North America had the second place and they were followed by South America, Asia, Europe and Africa. The most of the European universities were established in the past and their campuses had relatively less green areas than most of the participant Asian universities [20]. Hence, European universities were behind the Asia universities in the **SI** category. The **EC** category had the highest average in Europe, while North America had second higher average and Africa had the lowest. The reason why Europe comes to the fore in the **EC** category is that there are many universities study and practice on renewable energy. In the **WS** category North America was the leader due to the influence of the USA universities, which have better waste management applications in the university campuses. North America was followed by Oceania, Europe, South America, Asia and Africa continents. In the **WR** category North America had the highest average and it was followed by Oceania, South America, Europe, Asia and Africa. Europe had the highest average in the **TR** category. This result was related to the general lifestyle as well as university initiatives. Public transport and bicycle usage are very common in European countries. Therefore, the number fossil fuel vehicles entering the campus is less and the number of zero emission vehicles is higher than other countries. In the **ED** category, the highest average was in the Oceania continent and it was followed by Europe, North America, South America, Asia and Africa. The main reason for this is the institutional sustainability studies which have been initiated in the late 90s, especially at Australian universities [2]. As the Ragazzi and Ghidini (2017) **,** were previously stated in their study; the development level of countries has effect on overall results [19]. This theory supported by the performance results of the continents. The UI GreenMetric performance is generally higher in the developed countries.

3.3. Categories impacts on overall results

Evaluation information for the universities with the same score is not given in the guideline. Therefore, the 2019 ranking results were examined to understand the categories which have higher impacts on overall results According to the percentage weight of categories, the **EC** category is expected to be in the first place and it is followed by **WS, TR, ED, SI, WR** categories respectively. However, when the current ranking results are examined, it is seen that this is not the case. The **EC** category has the first place but impact of other categories is still not certain. In order to determine the second important category, universities with the same overall results and **EC** scores were compared. As it can be seen in Table 3 results have some uncertainties. In addition to the categories **alphabetical order** could be another parameter for ranking universities. Although the university that came first in alphabetical order was generally had higher ranking, exceptional cases were also observed.

Table 3. Selected ranking scores for comparing impacts of categories on overall results

Rank 2019	University	Country	SI	EC	WS	WR	TR	ED	Total Score	2nd possible category
42	Universidad AutónomaDe Occidente	Colombia	925	**1475**	1725	875	1200	1525	**7725**	WS ,ED, WR ,A
43	Western Michigan University	USA	1375	**1475**	1275	850	1375	1375	**7725**	
168	Pontificia Universidad Javeriana-Bogota	Colombia	625	**1300**	1125	450	1425	1350	**6275**	WS ,TR,ED,A
169	Universidad CES	Colombia	825	**1300**	1050	750	1200	1150	**6275**	
181	National Chin-Yi University of Technology	Chinese Taipei	625	**1050**	1200	600	1050	1650	**6175**	WS,ED
182	Maejo University	Thailand	1350	**1050**	825	600	1250	1100	**6175**	
195	Universidade de Vigo	Spain	850	**1250**	1275	625	1125	975	**6100**	WS,SI
196	Universidad De Antioquia	Colombia	550	**1250**	1125	750	1125	1300	**6100**	
198	University of Guilan	Iran	1125	**1100**	750	500	1125	1500	**6100**	TR,ED, SI,A
199	Universiy of Kufa	Iraq	950	**1100**	1125	825	925	1175	**6100**	
289	Universidad Autonoma Del Estado De Mexico	Mexico	700	**675**	1350	625	1025	1125	**5500**	WS ,ED, WR
290	Akdeniz University	Turkey	1050	**675**	1125	450	1225	975	**5500**	
315	University of Baghdad	Iraq	1100	**725**	600	500	1325	1100	**5350**	ED,SI, WR
316	Babes Bolyai University	Romania	825	**725**	750	300	1600	1150	**5350**	
318	Universidad Pontificia Comillas	Spain	275	**1100**	1125	650	950	1225	**5325**	ED, WR
319	Universita degli Studi di Padova	Italy	800	**1100**	1125	400	1025	875	**5325**	
319	Universita degli Studi di Padova	Italy	800	**1100**	1125	400	1025	875	**5325**	WS ,TR,A
320	University of Jordan	Jordan	900	**1100**	750	450	950	1175	**5325**	

Rank 2019	University	Country	SI	EC	WS	WR	TR	ED	Total Score	2nd possible category
414	Universidad de Pamplona	Colombia	775	**925**	825	350	825	1150	**4850**	WS,TR,ED
415	Razi University Kermanshah	Iran	975	**925**	675	600	775	900	**4850**	
433	Institut Teknologi Sumatera	Indonesia	850	**900**	750	575	875	775	**4725**	TR, WR,A
434	Islamic Azad University	Iran	1200	**900**	900	200	725	800	**4725**	
437	Yeditepe University	Turkey	725	**1050**	900	350	825	850	**4700**	WS ,TR,ED, WR
438	Saurashtra University	India	975	**1050**	825	300	800	750	**4700**	
502	Institute of Business Management	Pakistan	375	**1025**	900	500	825	750	**4375**	TR,ED,SI, WR
503	Bow Valley College	Canada	325	**1025**	1200	375	775	675	**4375**	
515	Voronezh State Technical University	Russia	500	**800**	900	450	700	975	**4325**	WS, WR
516	University of Kragujevac	Serbia	550	**800**	600	425	900	1050	**4325**	
612	Yazd University	Iran	1125	**500**	675	350	875	300	**3825**	SI, WR
613	Gorno Altaisk State University	Russia	425	**500**	750	275	900	975	**3825**	
700	University of Mosul	Iraq	900	**650**	75	0	700	375	**2700**	TR
701	Ivan Franko National University of Lviv	Ukraine	900	**650**	150	0	475	525	**2700**	
714	University of Kirkuk	Iraq	400	**425**	225	0	700	800	**2550**	ED
715	Universidad Autonoma De La Ciudad De Mexico	Mexico	450	**425**	300	200	950	225	**2550**	

A: Alphabetical order, SI: Setting & Infrastructure, EC: Energy & Climate, WS: Waste, WR: Water, TR: Transportation, ED: Education

3.4. Suggestions for the UI-GreenMetric Ranking System

Developers of the UI GreenMetric system were stated that an equal system for all universities is not possible by saying "*The different missions and perspectives created by these dimensions mean that the goal of finding indicators that are equally fair to all, seems practically impossible*". Also, they clarified that the UI GreenMetric is an entry level tool for sustainability activities for universities [7]. Despite that it is possible to make improvements in the system. Following assessments and suggestions were given for the improvement of the UI GreenMetric ranking system:

- All universities are entering the ranking list in the current UI GreenMetric system without any precondition. “**Baseline”** score was suggested in the previous academic study by **Ragazzi and Ghidini** [19]. According to previous study, universities should have minimum (baseline) score to have a place in the UI Green Metric ranking system like other sustainability ranking systems such as STARS. However, it is thought that all universities should be included in the ranking system in order to see the general trend in the world and also to make comparisons between countries and within countries.
- The ranking of universities could change due to change of other universities performances even though their overall performance is constant [19]. This situation was explained by **Ragazzi and Ghidini** as the **relativity of scores** problem [19]. Therefore, making a certain grouping or sustainability classes in the GreenMetric system will ensure that the sustainability performance of a university remains the same even if the overall place in the ranking changes.
- The UI GreenMetric has been a system that constantly renews itself over the years. **Sonetti et al. and Marrone et al.,** stated that this continues updating is the UI Green Metric’s strength [1], [20]. While **Ragazzi and Ghidini** indicated that changing indicators in the categories every year prevents making long-term plans [19]. Major changes were done in the UI Green Metric in 2012 and 2018, and minor changes were made in other years. Future major changes should be announced at least one year in advance to universities necessary time for preparation of next year application.
- The comparison between the ranking results and the score expectations of the universities will increase harmony and the transparency of the system. **Sonetti et al.,** recommended a "**satisfaction survey"** to strengthen the feedback system [1]. This survey should be done after the announcement of the ranking and it will enable universities to see the differences between expectations versus real results. Also, it will strength the assessment system of the UI GreenMetric.
- It is known that local conditions of university such as; size and location of the campus, university budget and other factors like old and new buildings affect the success of the sustainability plans [22]. Hence not only overall results but also categories should be examined in detail. **New certificates for categories** such as “energy efficient campus of the year”, “zero waste producer of the year”, “water-saver of the year”, “green path of the year” and “green producer/consumer of the year” are recommended. The awards of “categories” will help universities to highlight the subjects they are

successful in. Also, sharing the awarded projects on the UI GreenMetric website will be an incentive for new projects in other universities.

- The continent results in this study have shown that the development levels of the countries affect the UI GreenMetric results. Therefore, "**contribution to surrounding area sustainability**" indicator should be added in the **EC, WS** and **WR** categories for universities that positively affect basic life needs such as climate, waste and water management. The percentage weights of the categories may remain the same, but the addition of this indicator will encourage universities especially in developing countries.
- Details of the ranking system and **impacts of categories** on overall results should be clarified in the future in the UI GreenMetric's guidelines**.** Possible category descending order could be **EC, WS, ED, TR, SI** and **WR.**
- **The fee-free application** is one of the main reason why the UI GreenMetric is getting increasing attention from all over the world, hence fee-free applications should be continued despite the updates in the UI GreenMetric.
- In addition to the evaluation system, it would be a good option to award projects that directly address **global problems** such as "SDG-contributor" or "climate saver" in the annual GreenMetric workshops which are held every year.
- **Green purchasing** is another important factor for reaching institutional sustainability [23] and circular economy. Hence, purchasing indicator could also be added in the ranking system like in the STARS [24].
- Giving more importance to **social aspects** will help universities to embrace sustainability concept in the long term [1],[20]. Employee and student satisfaction indicators will cause increment in the social acceptance of the UI GreenMetric.

4. CONCLUSION

The UI GreenMetric has been getting great interest from all over the world since it was established. The UI Green Metric puts the green campus concept on the agenda of many universities, especially in developing countries. However, it is a fact that GreenMetric needs some updates and improvements. The exact effect of the UI GreenMetric categories should be clarified. It should be stated in the UI GreenMetric guideline that which parameters have priority while ranking universities. In order to understand the importance of categories and for creating successful projects, new awards for each category are recommended. The fee-free application to the UI Green Metric should continue in the future.

There is a significant increase in the number of published studies about green campus during last ten years. The possible effect of the UI GreenMetric on these studies should be analyzed in the future. Many universities carry out green campus projects under the management of "sustainability offices" in order to achieve more comprehensive results. The relationship between the UI GreenMetric ranking system performance of a university and the presence of sustainability office is also an important topic to be addressed. Although, ranking systems are important in terms of establishing standards and putting targets for universities they could cause a dilemma. After a certain point, universities may aim to be successful only in the ranking indicators. Hence, universities should put targets by considering their institutional weaknesses and they should aim more comprehensive targets such as SDGs.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest.

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The Effect of Acids on the Chemical Stability of UV Inkjet Prints on Papers with Straw Pulp

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Abstract

The bonding potential of pulp fibers is reduced by the paper recycling process. The most common technique for recovering this lost potential of secondary fibers involves upgrading the recycled pulp by blending it with virgin softwood pulps. In this research, we asses print stability on acid agents of UV inkjet prints when using straw pulp as reinforcing fibers in recycled papers. For that purpose, printing substrates were formed on the Rapid Köthen device from pulp obtained by blending different proportions of straw pulp and pulp of recycled fibers. Each printing substrate was printed in full tone with cyan, magenta, yellow, and black inks by digital technique of UV inkjet printing. Printed substrates were treated with various inorganic and organic acids under the conditions defined in the international standard ISO 2836:2004. Based on the measured spectrophotometric values of the untreated and acid-treated prints, the Euclidean color difference (ΔE_{00}^*) was defined and the stability of prints was assessed. The results of spectrophotometric measurements indicate small to medium color differences of the prints due to the effect of all acids ($\Delta E_{00max.}^* <$ 2.4) and it can be concluded that straw pulp in printing substrates from recycled fibers contributes to good chemical stability of prints. This research concludes that straw, as an annual renewable resource, can be used in conjunction with waste paper as an alternative to wood, which is currently the dominant raw material for graphic industry and producing paper.

Key words

Acids, Chemical stability, Paper, Straw pulp, UV inkjet printing

1. INTRODUCTION

Ink and printing substrate are the two components that have the greatest influence on image or text reproduction quality. Therefore, an adequate printing substrate is critical for any particular printing technique based on the function of the final product. Paper as the most commonly used printing substrate for all printing techniques is traditionally produced from cellulose fibers derived from wood. Over the last decades, the increased focus on waste paper recovery and use in paper and paperboard production was widespread due to environmental concerns. Substitution of virgin wood pulp by waste paper has been accepted globally, and today recovered paper accounts for around 50% of the total papermaking fibers worldwide [1]. It is important to emphasize that paper production

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cannot be based only on waste paper as a source of fibers, as it can neither be efficiently used for all paper grades, nor can it be used infinitely many times. However, depending on the final paper quality and its price, the utilization rates by paper grades vary significantly, ranging from 10% to more than 90%. In newsprint, the utilization rate is extremely high up to 92.8%, while in packaging papers it is, on average, 75.3%. For other graphic paper, it is only 10.6% [1]. In paper production from waste paper during the recycling process, it is important to continuously incorporate a certain amount of virgin fibers for strength, quality, and availability reasons. Given recycled fibers are not suitable for some products, as was already mentioned, the need for virgin fibers in the paper industry still exists. An alternative to conventional virgin wood fibers could be found in rapidly renewable sources (hemp, flax, bamboo, kenaf) and agricultural residues (wheat straw and bagasse) [2]. The great variety of characteristics, fiber dimensions and chemical composition of these alternative raw materials give them great potential to produce different types of papers [3]. The results of the previous study revealed that straw as an agricultural residue has fibers similar in length to hardwood species (common beech (*Fagus sylvatica L.*) and white poplar (*Populus alba L.*) which are most commonly used in cellulose and papermaking industries [4]. In addition, it has been proven that straw as non-wood plant material has nearly the same cellulose content as most wood species, lower content of lignin and higher amount of ash and solvent extractives [5]. The potential of wheat straw, the plant raw material that, according to annual yield, takes the first place in Europe and the second one in the world is recognized due to its availability which is one of the characteristics that a raw material for the paper industry must fulfill [6]. Wheat straw is applied as fibrous raw material for pulping and papermaking industry in countries with a lack of wood supply or in agricultural countries where this source is available in huge quantities [7]. However, if the paper made from straw pulp is intended for printing, the requirements for such papers are even higher. The printing substrates must hold most of the ink in the upper ten micrometers i.e. the ink layer should remain at or near the surface after drying in order to provide an optimum print density and good color saturation. But if the colorants are fixed to the surface of the printing substrate, they will be directly exposed to light, pollution, and other agents. Therefore, such print will be vulnerable to decomposition of the dye. Generally, the interaction of the ink with the substrate is key to producing high strength, well defined, durable images fit for any application [8].

As the quality and stability of the print directly depend on the composition of the paper as a printing substrate, it is important to determine which cellulose fibers (from the aspect of their origin) give quality prints. In this study emphasis is placed on evaluation of the straw pulp usability in the production of paper intended for printing based on the chemical stability of prints made on such substrates.

2. MATERIALS AND METHODS

2.1. Papers with straw pulp

Laboratory papers of approximately 42.5 g/m^2, formed by Rapid-Köthen sheet former (FRANK-PTI) according to standard EN ISO 5269-2:2004 [9], were made entirely of recycled wood pulp or from mixture of recycled wood and straw pulp of wheat, barley and triticale (Table 1.). Semi chemical straw pulp was obtained from crop residue leftover on fields after harvesting which was collected, manually cut, and processed by soda pulping method [10], [11].

Table 1. Papers used as printing substrates

Mark	Composition		Production type
	Straw pulp, %	Recycled pulp, %	
K	0	100	commercial
N	0	100	laboratory
1NW, 1NB, 1NTR	10	90	
2NW, 2NB, 2NTR	20	80	
3NW, 3NB, 3NTR	30	70	

* straw type: W = wheat; B = barley; TR = triticale

2.2. UV inkjet printing

All laboratory sheets and commercial paper were printed by digital EFI Rastek H652 UV curable inkjet printer. Each printing substrate was printed in full tone with cyan, magenta, yellow and black inks with the resolution of 600 × 600 dots per inch (dpi) (with high quality mode 8 pass) and printing speed of 12.10 m^2/ hr. In total 44 different UV inkjet prints were prepared for chemical stability analysis.

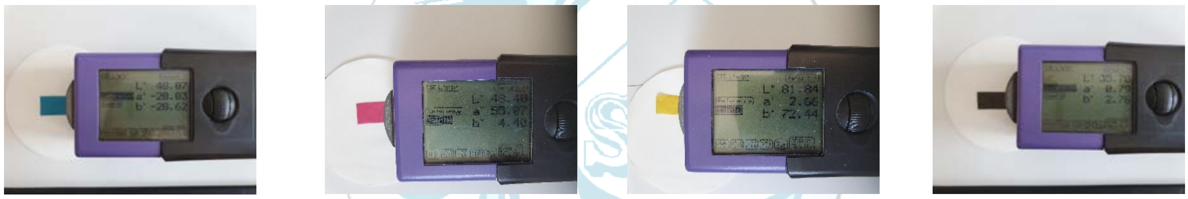
2.3. Chemical stability analysis

The method of assessing the resistance of printed samples to acid satisfied the international standard ISO 2836:2004 in the field of graphic industry [12]. All printed samples were cut to 2 cm x 5 cm dimensions before determining chemical stability. The treatment with acid solutions was performed as follows. First, two paper filters were soaked in an acid solution (v/v = 5%). They were then put onto the lower glass plate with a printed sample located in between. Finally, the upper glass plate is placed on top and weighted by a 1kg weight. The printed samples were thus exposed to each acid from 10 minutes to 60 minutes, depending on the type of acid (Table 2), after which each printed sample was washed with distilled water and dried in an oven for 30 minutes at 50 °C.

Table 2. Acids used as chemical agents and test conditions

Acid		Concentration % by volume	Receptor surface	Duration of exposure, min	Contact conditions
Inorganic	Hydrochloric (HCl)	5	filter paper	10	1 kg on 54 cm^2
	Sulfuric (H_2SO_4)	5		10	
Organic	Acetic (CH_3COOH)	5		30	
	Citric ($C_6H_8O_7$)	5		60	

Evaluation of chemical stability of UV inkjet prints on papers with straw pulp was done based on the Euclidean color difference (ΔE_{00}) which was calculated according to the equation (1). Colorimetric values were measured by spectrophotometer X-Rite SpectroEye before and after acid treatment (Figure 1.).



cyan magenta yellow black

Figure 1. Photographs of color data measurements on UV inkjet prints

Color data were measured under illuminant D50, 2° standard observers. The symbol ΔE_{00}^* is used to denote distance in the uniform color space [13] and is defined as:

$$\Delta E_{00}{}^* = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)} \quad (1)$$

Where: ΔE_{00}^* – total color difference, the Euclidean color difference

$\Delta L'$ – the transformed lightness difference between print before and after acid treatment

$\Delta C'$ – the transformed chroma difference between print before and after acid treatment

$\Delta H'$ – the transformed hue difference between print before and after acid treatment

R_T – the rotation function

k_L, k_C, k_H – the parametric factors for variation in the experimental conditions

S_L, S_C, S_H – the weighting functions

The results of change in visual perception of color due to the acid treatments are reported as an average of ten measurements from each print sample and interpretation of obtained ΔE_{00} values is summarized in Table 3.

Table 3. Interpretation of ΔE_{00}^* value [14]

ΔE_{00}^*	Color perception
≤ 1.0	Differences in color are unrecognizable by a standard observer.
1 - 2	Only an experienced observer is able to perceive the differences.
2 – 3.5	An inexperienced observer is able to perceive the differences.
3.5 - 5	Every observer can easily see the difference.
> 5	An observer recognizes two different colors.

If the color differences value after chemical treatment is lower than 2 it is defined as chemically stable print as very small or small noticeable difference in the tone can be recognized by standard observer. As the value of the Euclidean color difference increases, the change in color is more clearly visible by a standard observer.

3. RESULTS AND DISCUSSION

Inorganic and organic acids used as chemical agents have different strength in solution. Namely, inorganic hydrochloric (HCl) and sulfuric (H_2SO_4) acids are strong acids which means that in an aqueous solution they dissociate completely, while organic acetic (CH_3COOH) and citric ($C_6H_8O_7$) acids only partially dissociate in solution, so they are classified as weak ones. The quantitative measure of the strength of acid in a solution is defined by Ka value (acidity constant). Weak acids have very small Ka values and therefore higher values for pKa (pKa in range from -2 to 12) compared to strong acids, which have very high Ka values and slightly negative pKa values (pKa lower than -2).

The Euclidean color difference of UV inkjet prints on different printing substrates due to hydrochloric acid, sulfuric acid, acetic acid, and citric acid treatments are presented in Figures 2-5.

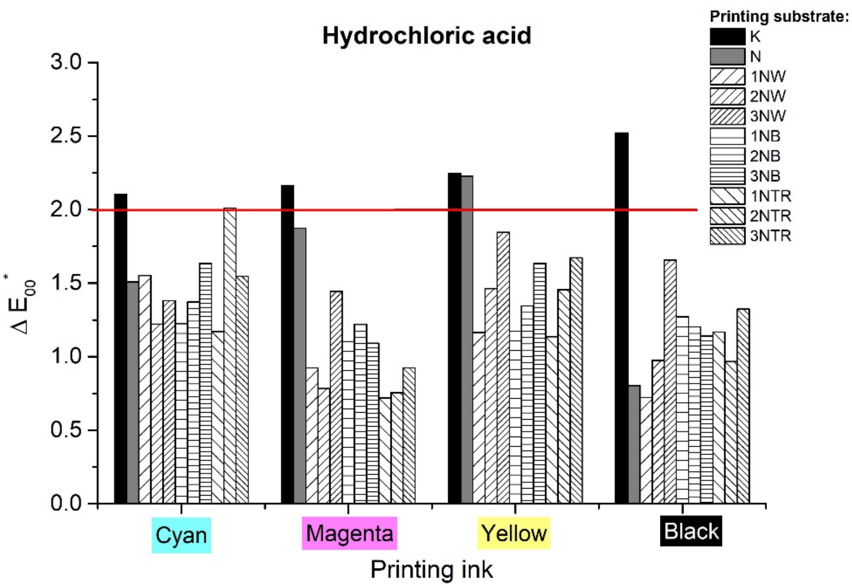


Figure 2. The Euclidean color difference of UV inkjet prints on different printing substrates after hydrochloric acid treatment

From gained results of spectrophotometric measurements of prints treated with hydrochloric acid presented at Figure 2, it is evident that commercial paper substrate (K) provides prints of lower stability in comparison with paper substrates produced at laboratory scale. However, CMYK prints on commercial paper substrate can be considered as satisfactory stable on hydrochloric acid because the change in color of the print is barely noticeable to a standard observer ($\Delta E_{00max.}^* < 2.4$). All laboratory papers provide good chemical stability of CMYK prints, especially those with addition of straw pulp. Generally, the most stable prints on printing substrates with straw pulp are those made with magenta and black (ΔE_{00}^* in range from 0.72 to 1.45 and 0.72 to 1.66, respectively).

Slightly larger changes in the quality of reproduction due to the hydrochloric acid treatment were noticed on the prints with cyan and yellow inks.

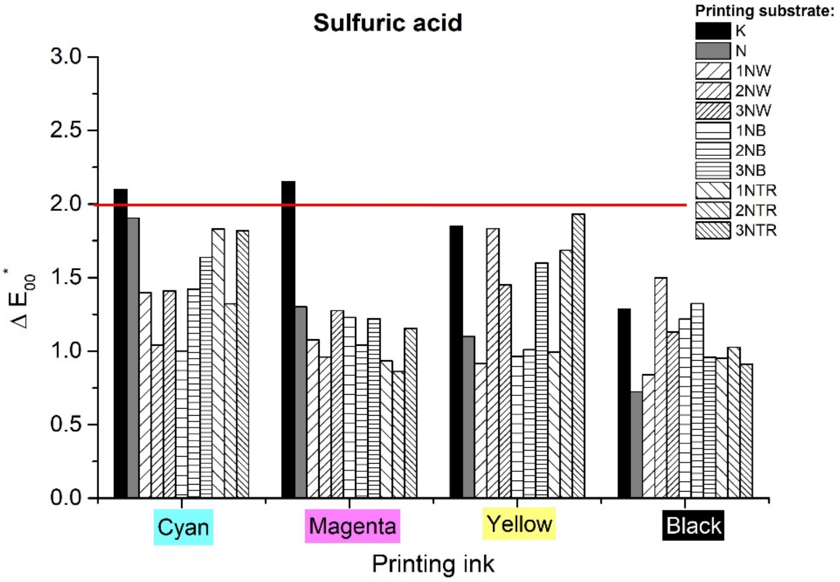


Figure 3. The Euclidean color difference of UV inkjet prints on different printing substrates after sulfuric acid treatment

The influence of sulfuric acid on color stability of UV inkjet prints is presented at Figure 3. The similar behaviour on CMYK prints was observed after sulfuric acid treatment but the values of the Euclidean color difference were slightly lower than due to hydrochloric acid treatment. Impact of sulfuric acid on the Euclidian color difference of prints is slightly more pronounced for magenta and cyan prints made on commercial printing substrate (K), while for yellow and black ink printed on commercial and laboratory printing substrates without straw pulp (N) or with straw pulp is approximately the same. The Euclidean color difference of prints on printing substrate with straw pulp is in range from 0.84 for black print on printing substrate with 10% of wheat pulp (1NW) to 1.93 for yellow print on printing substrate with 30% of triticale pulp (3NTR). Straw pulp of wheat, barley and triticale partially forms printing substrates which provide approximately the same stability to prints after treatment with strong hydrochloric and sulfuric acids.

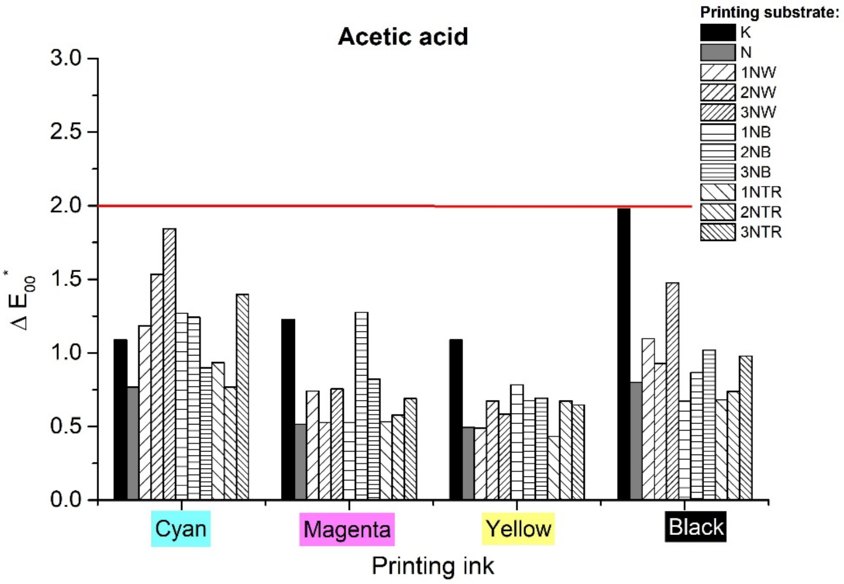


Figure 4. The Euclidean color difference of UV inkjet prints on different printing substrates after acetic acid treatment

Figure 4 presents results of acetic acid impact on chemical stability of UV inkjet prints on printing substrates with straw pulp. It is clearly visible that commercial printing substrate provides similar stability of prints as printing substrates made at laboratory scale, except for prints with black ink. The highest degradation on black print is measured on commercial printing substrate (K) with ΔE_{00}^* value of 1.98. The most stabile print, regardless on which printing substrate it is printed, is yellow (ΔE_{00}^* = 0.49 - 1.09). Cyan and black prints made on printing substrates with straw pulp have showed the highest degradation of color after acetic acid treatment (ΔE_{00}^* up to 1.84).

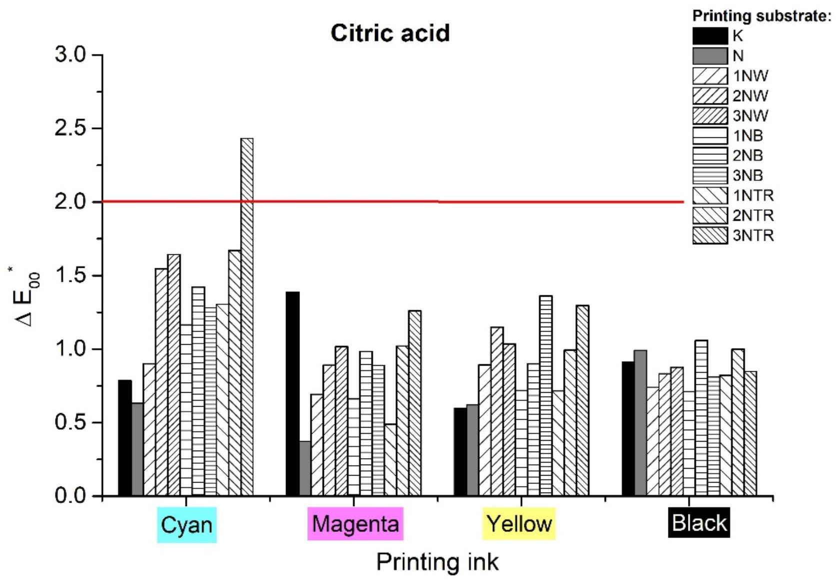


Figure 5. The Euclidean color difference of UV inkjet prints on different printing substrates after citric acid treatment

The influence of citric acid on degradation in color of UV inkjet prints is presented at Figure 5. The highest degradation of color by this organic acid is observed on cyan prints (3NTR printing substrate with ΔE_{00}^* = 2.43), while magenta, yellow and black prints show similar color degradation.

As citric and acetic acids are weaker than inorganic acid used for chemical stability assessment their effect on prints is smaller. Generally, for all printed inks the Euclidean color difference values after treatment with these organic acids are lower than 1.5. It is interesting that for organic acid treatment the type of paper production (commercial or laboratory) did not show significant differences in chemical stability of prints as with strong inorganic acids.

4. CONCLUSION

The main aim of this research was to evaluate the usability of straw pulp for paper production intended for printing based on the chemical stability of UV inkjet prints on such printing substrates after acid treatment. As the results of spectrophotometric measurements indicated by a standard observer unrecognizable or hardly perceive color differences for all four analyzed colors due to the action of inorganic or organic acids ($\Delta E_{00max.}^*$ < 2.4) it can be concluded that addition of straw pulp in printing substrates contributes to good chemical stability of prints. This research concludes that straw, as an annual renewable resource, can be used in conjunction with waste paper as an alternative to wood, which is currently the dominant raw material for graphic industry and producing paper.

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Analysis of Natural and Artificial Aging Influence on UV Inkjet Prints on Printing Substrates with Straw Pulp

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Abstract

Paper substrate, as the most common used substrate for printing labels or packaging, is traditional produced from cellulose fibres derived from wood. The growth of a large number of industries has led to a significant increase in the use of such resource, which consequently led to a global awareness of the possibility of forest exploitation and the importance of reusing waste paper as a source of fibres. Hence, paper fibres can be recycled up to seven times and it is important to enrich paper pulp with virgin fibres during paper production. In such a way, the characteristics of the paper and the quality of the printed elements are improved. In this paper, cereal straw as an alternative resource of virgin fibres was turned into pulp and mixed with recycled wood pulp to conduct printing substrates using laboratory equipment. Since aging is an inevitable process of any printing substrates and prints, and the degradation of print quality due to aging largely depends on the properties of the printing substrate, ink and type of printing. This research was focused on analysing optical stability of prints made on printing substrates with straw pulp by UV inkjet technique after natural and artificial aging. From a comparison of the aging processes based on the Euclidean difference results, it was observed that natural aging of UV inkjet prints yields less colour changes compared to artificial aging. Greater or equal optical stability after aging was perceived for prints on printing substrates with wheat, barley and triticale pulp compared to prints on substrates made with recycled wood pulp.

Key words

aging, optical stability, printing substrate, straw pulp, UV inkjet printing

1. INTRODUCTION

Aging can be defined as irreversible changes that occur slowly over time [1], and in the case of paper and print this process may result in deterioration of useful properties, resulting in an unsuitable final graphic product. Although cellulose due to accidental hydrolysis of glycosidic bonds between glucose residues into cellulose macromolecules, oxidation and crosslinking affects the natural aging of paper, it is shown that the energy radiation, temperature and relative humidity (RH) are crucial to the longevity of paper substrate. The degree of polymerization (DP) of cellulose is also been reduced by aging process which causes deterioration of the optical properties of the cellulose and thus paper as a sheet made from randomly deposited cellulose fibres in network. The deterioration in print quality due to aging is largely dependent not only on the properties of the paper as a printing substrate, but also on the ink and type of printing process [2].

Since paper substrates have been traditionally produced from wood-derived cellulose fibres, the consumption of wood raw materials has increased significantly in recent years, which led to a global awareness of the possibility of forest exploitation and the importance of reusing waste paper as a source of cellulose fibres.

Over the past decade, the use of recovered paper in the paper and cardboard industry has grown all over the world. Recycled paper makes up about 50% of the total production of paper fibres used worldwide. The utilization rates of recycled paper substrates are very different, depending on the desired quality and final purpose. In the year 2010, the main purpose of recycled paper in Europe was for packaging production with 63.7%, for publications with 26.0% (18.6% for newsprint and 7.4% for other graphic products), for household and sanitary with 6.9%, and only 3.4% for other paper grades [3]. Substitition virgin wood fibers with recycled ones fiber also reduces greenhouse gas emissions by about 37% [4]. Paper production cannot be supplied only with recycled fibres derived from waste paper, because they cannot be used effectively in all paper grades, nor can be used indefinitely as raw material. Therefore, recycled pulp needs to be enriched with a certain amount of virgin fibres in order to increase the strength (wood cellulose fibres decay with each recycling process) and the quality of the paper [3].

Many countries around the world are struggling with the forest shortages, and this problem would become even greater in the coming years. Aware of this environmental problem, researchers are constantly introducing alternative sources of cellulose fibres. Alternative resources of non-wood virgin fibres are divided into this groups: purpose dedicated crops, agricultural residues, industrial residues and uncultivated crops that occur naturally [5]. The most widely used are cane bagasse, bamboo, kenaf, hemp, sisal, abaca, cotton linter and reeds, as well as some exotic raw materials like aquatic plants, tea waste, palm leaf and banana stem. Most of these plants are annual plants that develop the full potential of fibre in one growing season [6].

Printed paper substrates are frequently used in a variety of everyday applications, from newspapers to packaging material and labels. Since the colour durability and permanence of a graphic product plays an important role in ensuring accuracy, prints should not be degraded in quality before the product is sold or during usage [7]. Therefore, this research is focused on the analysis of optical stability of prints made on printing substrates without and with straw pulp by UV curable inkjet digital technique after natural aging and artificial aging. Laboratory printing substrates made with cereal straw were compared to laboratory printing substrates made only from recycled fibers which are used as reference paper (N), while commercial printing substrates were used as control substrate (K).

2. MATERIALS AND METHODS

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2.1. Papers with straw pulp

The straw of the most common crop species in Croatia: wheat (Triticum spp.), barley (Hordeum vulgare L.) or triticale (Triticale sp.) straw were collected after the harvest and manually cut using scissors into 3 cm long pieces. Purified straw was conducted into semichemical pulp according soda pulping method [8]. Laboratory papers of approx. 42.5 g/m2 were formed by Rapid-Köthen sheet former (FRANK-PTI) according to standard EN ISO 5269-2:2004 [9] whereby straw pulp (wheat, barley or triticale) was added in proportions of 10%, 20% or 30% into reference pulp of recycled paper (Table 1).

According to their composition, 10 different laboratory papers were formed and compared to each other and observed in relation to commercial paper made from recycled wood pulp.

Table 1. Commercial paper and laboratory papers composition

MARK OF SUBSTRATE	COMMERCIAL PRINTING SUBSTRATES - COMPOSITION
K	Commercial paper - 100% recycled wood pulp
MARK OF SUBSTRATE	**Laboratory printing substrates - Composition**
N	100% recycled wood pulp - reference paper
1NW	10% wheat pulp + 90% recycled wood pulp
2NW	20% wheat pulp + 80% recycled wood pulp
3NW	30% wheat pulp + 70% recycled wood pulp
1NB	10% barley pulp + 90% recycled wood pulp
2NB	20% barley pulp + 80% recycled wood pulp
3NB	30% barley pulp + 70% recycled wood pulp
1NT	10% triticale pulp + 90% recycled wood pulp
2NT	20% triticale pulp + 80% recycled wood pulp
3NT	30% triticale pulp + 70% recycled wood pulp

2.2. UV curable inkjet printing

In order to analyze changes in optical properties of printed commercial and laboratory substrates, both sample types were printed by digital EFI Rastek H652 UV inkjet digital machine at ambient conditions of 55% RH and temperature of 23°C. Cyan, magenta, yellow and black UV curable inks were printed in fulltone on each laboratory paper and commercial paper with the resolution of 600 × 600 dots per inch (dpi) (respectively with high quality mode 8 pass) and printing speed of 12.10 m2/ h. EFI Rastek digatal machine uses the Toshiba Tec CA-5 printhead for each color. These printheads offer the ability to print grayscale, which means it can produce droplets of different sizes from 6 pl to 42 pl, which creates prints of the higher quality.

Figure 1. Printed commercial and laboratory substrates

2.3. The process of prints aging

The experimental part of this research was divided into two parts to conduct the two types of aging processes: artificial aging and natural aging.

2.3.1. Artificial aging process of prints

Printed commercial and laboratory paper substrates without and with straw pulp were shaped into 60 mm x 90 mm strips and placed side by side on a white background in the Suntest XLS + test chamber. The imitation of natural aging treatment was performed by xenon lamp with a daylight filter, emitting visibly and close to ultraviolet electromagnetic radiation with the wavelength in a range from 290 nm to 800 nm.

The artificial aging procedure was performed in two cycles of 48 hours according to ASTM D 6789-02 [10], during which the light intensity level was 765 ± 50 W/m^2.

Table 2. Conditions during artificial aging treatment

Cycle of aging	Duration of the aging process (h)	Heat flow rate intensity (J/s·m^2)	Ambient condition	
			Temperature (°C)	Relative humidity (%)
I	48	765	24.8	54.7
II	96	765	23.5	47.4

2.3.2. Natural aging process of prints

The printed samples were stored during period of 365 days side by side in a black bookcase in a dark and dry place to analyse the influences of the natural aging process.

Spectrophotometric analysis

Spectrophotometric measurements in the visible part of electromagnetic spectrum were performed before and after aging processes on all printed substrates by SpectroEye device, X-rite (D50, 2°). Spectrophotometric measurements provided data on the optical properties of analysed prints that were observed using colorimetric characteristics by CIE L*a*b* values. The colorimetric values L*a*b* were used to define the optical degradation of printed substrates, before and after aging processes, which were ultimately presented on the basis of Euclidean differences (ΔE_{00}*). Colour difference or Euclidean difference (ΔE_{00}*) is the numerical value for describing difference between two colours. Analysing of optical stability of cyan, magenta, yellow and black UV inkjet prints without and with straw pulp was determined based on Euclidean color difference which was calculated according equation (1).

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)} \qquad (1)$$

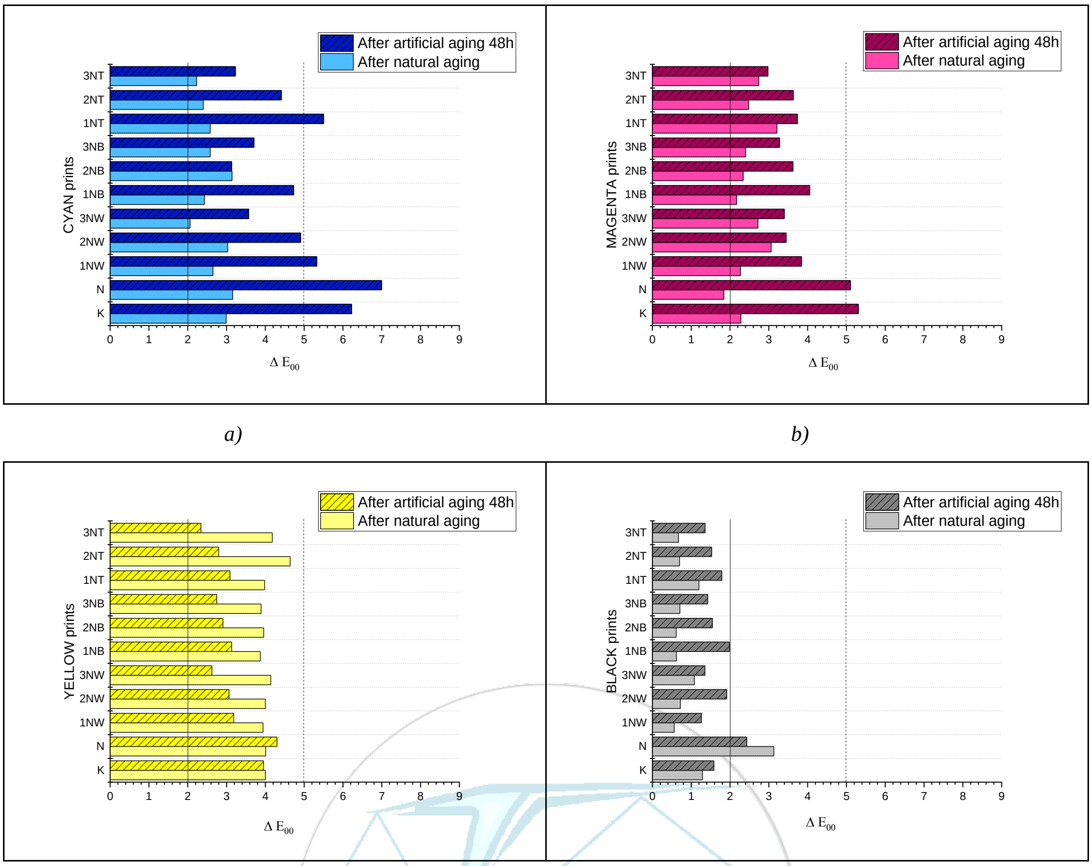
Values ΔL' (lightness), ΔC' (chroma) and ΔH' (hue) are calculated based on the colorimetric values of the analysed prints after the aging process L^{*1}, a^{*1}, b^{*1} and the colorimetric values of prints before aging process L^{*2}, a^{*2}, b^{*2}, where ΔL', Δa*, Δb* are differences between colorimetric values of the print after aging and colorimetric values before aging process, R_T is the rotation function S_L, S_C, S_H are weighting functions for lightness, chroma and hue, factors k_L, k_C, k_H are defined with respect to observation conditions. In the CIE L*a*b* colour space the value L' represents the lightness of the colour and the value +a* represents redness or the value –a* represents greenness, and the +b* value represents yellowness or the value –b* represents blueness [11,12]

According to Euclidean differences definition ΔE_{00}*≤ 2 is classified as very small noticeable difference for standard observer, while ΔE_{00}*=5 is defined like a big noticeable difference in the colour whose standard observer can recognized [13].

Figure 2. Spectrophotometric measurements

3. RESULTS AND DISCUSSION

Comparison of optical stability of prints performed on papers without and with straw pulp after first artificial aging cycle of 48 hours and natural aging process observed on the basis of the Euclidean difference is presented in Figure 3.



a) b)

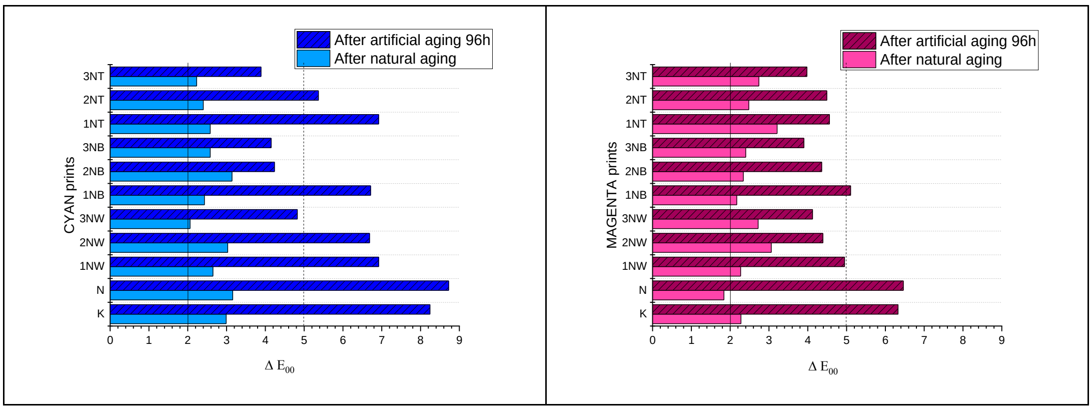
c) d)

Figure 3. The comparison of the first cycle of artificial aging and natural aging processes based on the Euclidean colour difference of cyan (a), magenta (b), yellow (c) and black (d) UV inkjet prints

According to spectrophotometric measurements the addition of wheat, barley and triticale pulp into laboratory substrates provide equal or slightly greater optical stability during aging process. Observing all results it could be assumed that magenta and cyan prints made on the reference paper (N) and commercial paper (K) show the most pronounced changes in the coloration after the artificial treatment of 48 hours while the less visible changes are observed on printed substrates with the addition of straw pulp. From obtained results of all yellow prints it is evident that printed substrates with the addition of straw pulp have slightly larger colour changes during natural aging than after first cycle of artificial aging treatment.

Given treatments of aging, black prints have similar behaviour as cyan and magenta prints. After both of observed aging treatments, a slight reduction in the colour of the black print was obtained, which is defined according to tolerance definition as a small noticeable difference in the tone that standard observer can recognize. Generally, the most stable prints, regardless of the substrate composition, are those obtained with black UV inkjet ink, where the largest Euclidean colour difference after natural aging is $\Delta E_{00(N)} = 3.2$, while the Euclidean colour difference after artificial aging is up to $\Delta E_{00(N)} = 2.43$.

The comparison of optical properties of prints performed on papers without and with straw pulp after second artificial aging cycle (in total 96 hours) and natural aging process observed on the basis of the Euclidean difference is presented in Figure 4.



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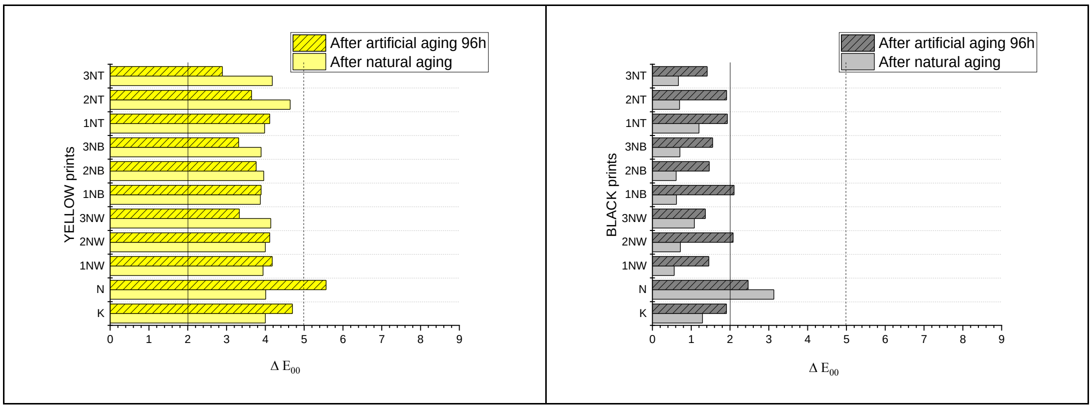

c) *d)*

Figure 4. The comparison of the second cycle of artificial aging and natural aging processes based on the Euclidean colour difference of cyan (a), magenta (b), yellow (c) and black (d) UV inkjet prints

From the Figure 4 it is visible that greater colour deviations were obtained on all printed substrates without and with wheat, barley or triticale pulp after artificial aging period for 96 hours, which are defined as significant noticeable difference in the print tone that standard observer can recognize.

From the value of Euclidean colour difference, it is noticeable that the colour degradation of the UV inkjet prints decreases with the gradual addition of straw pulp in laboratory substrates.

When comparing colour difference after second artificial aging treatment and after natural aging process it is possible to define that 96-hour artificial aging treatment yielded the same colorimetric differences as the natural aging on yellow printed substrates, regardless of the substrate composition.

The black UV inkjet ink on the prints after a longer period of artificial aging treatment provides the most stable prints on all observed printed substrates, where the highest colorimetric difference goes up to a value of $\Delta E_{00(N)} = 3.3$.

4. CONCLUSION

Based on obtained data from the comparison of the aging processes, the following conclusions can be drawn:

- Prints on laboratory substrates which containing wheat, barley or triticale straw pulp have the greater optical stability after artificial aging treatments compared to printing substrates made from recycled wood pulp.
- The greatest optical instability after natural aging was noticed for yellow prints on all printing substrates, while only after artificial aging of 96 hours the same colorimetric differences were obtained as after natural aging.
- Cyan, magenta and black prints obtained on printing substrates with and without straw pulp after natural aging for a period of one year have shown greater stability compared to prints after artificial aging treatment.
- The greatest ability to remain chemically and physically stable over long periods of time was noticed for black prints on all observed substrates.
- Experimental observation of optical stability confirmed that laboratory papers with addition of straw pulp could be used for certain categories of printing papers, such as for packaging, labels or some publications.

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